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Experiments in Steady State Crossed-Field Acceleration of Plasma

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THIS letter reports successful experiments in the steady state acceleration of plasma with linear, dc, crossed-field accelerators at a moderately high density. These experiments were carried out on a small scale. A rather conventional 150-kw arc jet, with the discharge rotated by a magnetic field, was used to heat a flow of $2\frac{1}{2}$ g/sec of nitrogen at about 1 atm pressure to a stagnation temperature of about 7000°K, as determined by calorimetric measurements of the cooling water. The heated nitrogen was seeded with cesium vapor to provide a plasma with a degree of ionization of a few percent. The plasma flowed through a supersonic nozzle to become a Mach 2 flow with a cross-sectional area of 1 sq cm. The plasma then flowed through an accelerator channel across which were applied magnetic and electric fields normal to each other. The accelerators were constructed of boron nitride and had lanthanum hexaboride or thoriated tungsten cathodes and carbon anodes. The electrodes were flat rectangular plates set flush with the upper and lower walls of the channel. The cathodes were not previously activated and were heated by the plasma to provide thermionic emission. The channels had lengths of 2 to 7 cm and had either one or seven pairs of electrodes. Magnetic fields of 4000 and 11 000 gauss and electric fields of 30 to 50 v/cm were used. Current densities of 6 to 30 amp/cm² were obtained. Measurements of Pitot pressure were made with a Pitot tube in the exit flow from the channel. During the runs, which usually were of 30 sec duration, switches in the circuits that applied the electric field were alternately closed and opened each 5 sec and the Pitot pressure was continuously recorded. In various runs, the increase in the stagnation pressure of the flow when the switches were closed amounted to 5 to 25% of the stagnation pressure (which latter was about 400 mm Hg) when the switches were open. These increases can be expected to be the net result of an increase due to acceleration by the Lorentz force and decrease due to Joule heating. This is believed to be the first successful operation of a steady state crossed-field plasma accelerator at moderately high density.

An approximate check with theory was made by using an equation from reference 1, written in the MKSQ system, for the theoretical change in stagnation pressure due to the Lorentz force and Joule heating

$$\frac{\Delta H}{H\,\Delta x} = \frac{\gamma M^2}{2 + (\gamma - 1)M^2}\left[\frac{2jB}{\rho u^2} - (\gamma - 1)\frac{M^2 j^2}{\sigma \rho u^3}\right]. \quad (1)$$

Measured values of stagnation pressure H, accelerator length Δx, magnetic induction B, and mass flow rate per unit area ρu were used. The measured current was used to obtain the current density j under the assumption of uniform distribution. The specific heat ratio γ was calculated to be 1.35 at the temperature taken from a Mollier diagram, Mach number M was calculated from the area ratio of the nozzle, and the conductivity σ was calculated by Eq. (51.1) of reference 2, in which the degree of ionization was calculated from the measured rate of seeding and Saha's equation, electron-neutral and ion-neutral interaction parameters were obtained from data on mobilities and adjusted for temperature, and the electron-ion interaction parameter was calculated from theory. [The second term in the square bracket of Eq. (1) was usually less than 10% of the first term.] For various runs, the measured values of ΔH were between 45 and 95% of the thus-obtained theoretical values.

Although very much research and development remain to be done on this kind of plasma accelerator, the experiments at least indicate the eventual possibility of its use as a source of high-speed flow for aerodynamic testing, magnetohydrodynamic research, and spaceship propulsion and maneuvering.

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[1] G. P. Wood and A. F. Carter, "Considerations in the design of a steady-flow dc plasma accelerator," in *Dynamics of Conducting Gases*, edited by A. B. Cambel and J. R. Fenn (Northwestern University Press, Evanston, Illinois, 1960), p. 209.

[2] W. Finkelnburg and H. Maecker, *Handbuch der Physik* (Springer-Verlag, Berlin, 1956), Vol. XXII.